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Methods for Performance-Testing of Electromechanical Pressure Transducers

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Electronic Instrumentation Division
Institute for Applied Technology

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Methods for Performance-Testing of Electromechanical Pressure Transducer

P. S. Lederer

This publication describes methods in one particular program at NBS for the performance-testing of electro-mechanical pressure transducers (such as telemetering transducers used in aerospace testing.) It covers static and dynamic calibration procedures in detail, delineates environmental and other tests, and describes the test equipment used. Examples of dynamic calibration results are interpreted.

KEY WORDS: Electro-mechanical, Pressure, Transducer, Calibration, Performance, Test method, Dynamic Calibration, and Telemetering.

1. Introduction

This publication describes methods used in one particular program at NBS for the performance testing of electro-mechanical pressure transducers (such as telemetering transducers used in aerospace testing). In order to obtain meaningful measurements of physical quantities such as pressure, acceleration, and temperature, by the use of telemetering transducers, one must have thorough and accurate knowledge of the performance characteristics of such transducers. This report describes the test methods currently used in the Basic Instrumentation Section of NBS to determine the characteristics of one class of instruments: electro-mechanical pressure transducers. The main objective is to present a group of test procedures which have been developed during the past several years as part of the "Interagency Telemetering Transducer" program at the National Bureau of Standards, currently supported by agencies of the Defense Department and NASA. These procedures permit the effective determination of performance of a pressure transducer. Tests to destruction were not carried out as part of this program. No attempt has been made to describe and review critically all the known methods for testing this class of transducers.

The terms defined below deal with those characteristics of an electromechanical pressure transducer which, at the present state of the art, a user should be in a position to evaluate. The manufacturer, on the other hand may be expected to furnish information on these characteristics.* The letter index refers to location of definition in the following Section 1.1:

(L) contact resistance
(M) coulomb damping

(K) dynamic response
(B) full scale output
(F) hysteresis
(E) linearity
(I) lowest frequency of resonance
(U) mounting torque, effects of
(S) power supply variations, effects of
(V) pressure cycling effects
(A) range
(H) repeatability
(G) resolution
(J) rise time
(C) sensitivity
(P) steady-state acceleration response
(W) storage effects
(R) thermal gradient effects
(N) thermal sensitivity shift
(O) thermal zero shift
(Q) vibrational acceleration effects
(T) warm-up effects
(D) zero-pressure output

1.1 Performance Characteristic Terminology For Pressure Transducers

A. Range: The values of pressure over which the transducer is intended to measure, specified by their upper and lower limits. For test purposes this is taken as the nominal values by which the manufacturer classified the transducer; e.g. 0-50 psig, ±3 psid, 0-15 psia.

B. Full-Scale Output: The algebraic difference between the electrical output values at the upper and lower limits of the range at a specified excitation (may be given as "full-scale").

C. Sensitivity: The ratio of the relative change in transducer output to the change of the pressure causing it at laboratory ambient conditions. For linear devices sensitivity is taken as the slope of the

* In the past some confusion has resulted from the fact that the manufacturer's published data and the users evaluation data were not developed from the same type of test. The Instrument Society of America through its Survey Committee on Transducers for Aero Space Testing (SCOTFAST) has been engaged in a continuing effort to promulgate uniform terminology and test methods in the field of aerospace transducers and the definitions of terms listed below are based with minor modifications on definitions which appear in tentative recommended practices which have issued from that committee and were used with permission of ISA. (1, 2)

computed (least squares) best straight line through all calibration points during a careful static calibration at stated environmental conditions. It is usually expressed in terms of millivolts output per volt (milliampere, when operated with a constant current supply) excitation per pound per square inch for straingage pressure transducers and in terms of voltage ratio per psi for potentiometric pressure transducers.

D. Zero-Pressure Output: The electrical output of the transducer when the sensing end of the transducer is exposed to ambient atmospheric pressure. Its value is expressed as a percentage of full-scale output at a specified excitation.

E. Linearity: The maximum deviation of any calibration point from the corresponding point on a specified straight line during any one static calibration cycle at stated environmental conditions. It is expressed as a percentage of the full-scale output.

Unless otherwise indicated the straight line is that one for which the sum of the squares of the residuals is minimized for all points obtained ("least squares linearity").

F. Hysteresis: The maximum difference in electrical output at any pressure value within the transducer range, when the value is approached first with increasing and then with decreasing pressure. It is expressed as a percentage of the full scale output at specified excitation. It is determined by a static calibration with applied pressure changing monotonically from zero to full range and monotonically back to zero. The prevailing environmental conditions and the time elapsed for calibration over the loop should be stated.

G. Resolution: The smallest increment of pressure input at a specified pressure which can be detected as a change in the electrical output. It is expressed as a corresponding percentage of the full scale output at specified excitation.

H. Repeatability: The maximum difference between values of certain characteristics (sensitivity, zero pressure output, etc.) obtained by specified repeated uni-directional static calibrations at stated environmental conditions. It may be expressed as a fractional change in percent. "Repeatability of sensitivity" and "repeatability of zero pressure output" are commonly sought. The total period of time over which the calibrations extend has a critical influence on the values obtained and must be stated such as "repeatability of sensitivity over period of ___ minutes", or "repeatability of zero output over period of ___ months".

I. Lowest Frequency of Resonance: The lowest of the frequencies at which the transducer output peaks to a maximum with constant amplitude pressure oscillation or the lowest of the frequencies at which the transducer will freely oscillate when subjected to a step function of pressure.

For transducers with very little damping (which is the case for most pressure transducers) the frequencies obtained by the two approaches above, will be found to have approximately the same value. The term "natural frequency" should only be used in reference to a true single-degree of freedom system such as most spring-mass accelerometers. Pressure transducers in general, appear to be multi-degree of freedom systems. Their lowest frequency of resonance largely determines the frequency response of these transducers, particularly of "flush diaphragm" transducers.

J. Rise time: The length of time for the output of a transducer to rise from a small specified percentage of its steady state value to a large specified percentage of its steady state value before overshoot or in the absence of overshoot, when subjected to a step input. For "cavity" pressure transducers, the rise time is a function of geometry and acoustic properties of the cavity and frequently imposes limitations on the frequency response of such transducers quite apart from the lowest frequency of resonance.

In this laboratory rise time is taken as the time from the beginning of the pressure step until the transducer output first reaches the computed value of the pressure step. In the experimental determination of this value care should be taken that the rise time of the applied pressure is one-third or less of the rise time of the transducer.

K. Dynamic response: The ratio of the computed output value of the transducer to the corresponding transducer output when it is subjected to a pressure step at a specified time after the beginning of the step. It is preferrable to make the comparison after the initial step-excited "ringing" of the transducer has died down. Testing time limitation, such as imposed by th short duration of a shock-tube generated pressure step, may require comparison during "ringing". This may be done by striking an average between the peak extremes of this oscillation.

L. Contact Resistance: The estimated peak-to-peak variation in resistance between the sliding contact when in motion and the resistance winding of a potentiometric pressure transducer with a specified current through the winding. This is expressed in ohms of variation or as a percentage of the total winding resistance.

M. Coulomb Damping (Dry Friction Damping): Velocity-independent damping occuring when one solid rubs against another, such as the sliding contact on the potentiometer element producing changes in output value. This is expressed as a percentage of full scale output.

N. Thermal Sensitivity Shift: The change in sensitivity due to a specified change in ambient temperature. It is usually expressed as a percentage of the sensitivity (at laboratory ambient conditions) per unit temperature change. If the temperature-sensitivity characteristic is not linear, it can be expressed as the maximum percentage change of sensitivity over a temperature range specified by two temperature limits. The transducer must be allowed to stabilize at each test temperature.

O. Thermal Zero Shift: The change in zero pressure output due to a specified change in ambient temperature. It is usually expressed as a percentage of the full scale output (at laboratory ambient conditions) per unit temperature change. If the temperature-zero-pressure output characteristic is not linear, it can be expressed as the maxi percentage change of zero pressure output over a temperature range s fied by two temperature limits. The transducer must be allowed to lize at each test temperatuare.

P. Steady-State Acceleration Effects: The effect on zer sure output at laboratory ambient conditions of the application c stant values of acceleration for a period of time of the order o along specified axes of the transducer. It is expressed as a p of full scale output per unit acceleration.

Q. Vibrational Acceleration Effects: The output at laboratory ambient conditions caused by the application of vibrational accelerations of specified amplitude and range of frequencies along specified axes of the transducer. It is expressed as a percentage of full scale output per unit vibrational acceleration over a specified frequency range. If a mechanical resonance is found during the test, its frequency must be given.

R. Thermal Gradient Effects: The effect on zero pressure output of the thermal gradient due to the application of a step function of thermal energy to the sensing element of the transducer. It is described as the maximum change of zero pressure output during a specified time interval commencing with application of a thermal input of specified magnitude. The time at which this occurs should also be given.

S. Effects of Power Supply Variations: The effect on sensitivity and zero pressure output of changes in the excitation voltage or current from nominal values. Expressed in percentage sensitivity change per unit excitation change and in zero output change (as percentage of full scale output) per unit excitation change.

T. Warm-up effects: Changes in sensitivity and zero pressure output at laboratory ambient conditions with time one minute after the transducer is connected to a well stabilized excitation source until stability of both characteristics is achieved. This is expressed as sensitivity and zero output changes in percentages during the time interval required for stability.

U. Effects of Mounting Torque: Changes in sensitivity and zero pressure output at laboratory ambient conditions due to different values of mounting torque. This applies primarily to "flush diaphragm" pressure transducers. These changes are described in terms of percentage per unit change of mounting torque.

V. Pressure Cycling Effects: Changes in sensitivity, zero pressure output, linearity, and hysteresis when the transducer is subjected to repeated application of a specified value of pressure (usually within the range of the transducer). Expressed in terms of percentage after specified number of pressure cycles.

W. Storage Effects: Changes in sensitivity, zero pressure, output, linearity and hysteresis, while and after transducer has been kept under specified environmental conditions. Expressed in terms of percentage.

2. Static Calibration

The basic equipment for static calibration consists of a source of known pressures, a source of electrical excitation for the transducer and devices for the measurement of the electrical output of the transducer and of the electrical excitation.

The initial static calibrations of the transducer at laboratory ambient conditions furnish the base to which all performance characteristics are referred. These calibrations must therefore be performed with especially great care. Subsequent static calibrations may be less elaborate than the initial ones, but still require careful procedure.

2.1 Static Calibration Equipment

2.1.1 Pressure Source

Dead weight piston gages are used as sources of known pressure. A commercial device with air as the pressure medium is used to supply pressures between 0.3 psi and 500 psi. Transducers with larger ranges are calibrated by means of another dead weight piston gage using oil. The use of air as a pressure medium is preferred for its cleanliness and because it simplifies transducer calibration at low and high temperatures.

A dead weight piston gage consists basically of a piston inserted into a closely fitting cylinder. Weights loaded on one end of the piston are supported by fluid pressure applied to the other end. The pressure generated can be measured in terms of force and area. With the axis of piston and cylinder vertical, the force is due to the gravitational attraction between earth and the weights. During operation the weighted piston is rotated to reduce friction.

Possible sources of error include uncertainties in the knowledge of the mass of the loading weights, the effective areas of piston and cylinder, air buoyancy of the weights, value of local gravity, leveling of piston gage, thermal expansion of piston and cylinder, elastic deformation of piston and cylinder force on the piston due to surface tension, fluid buoyancy on the piston, and fluid heads existing in the system. The last four can be effectively ignored for air-piston gages. For liquid filled piston gages, the necessary corrections can readily be made (3).

For the air piston gage used, the necessary corrections for local gravity, temperature and buoyancy of the weights are made with aid of a nomogram in the manufacturer's instruction book. Incorrect leveling may be a source of error: An uncertainty of ± 1/2° may cause an error of ±0.004% of the reading. The uncertainty of the value of pressure generated by such a piston gage may be expected to be less than ±0.05% of the pressure at pressures up to 500 psi. This is entirely adequate for the testing of this class of pressure transducers.

The air piston gage is supplied with breathing quality air or dry nitrogen through a pressure regulator, from a storage tank for pressures above 90 psi or the laboratory air line for lower pressures. The regulator is used to approximate the desired pressure and a variable-volume device is used for the fine adjustments required to float the piston and loading weights in the proper position to supply the desired pressure. For calibration above 500 psi, this laboratory uses an oil-filled dead-weight piston gage of only intermediate accuracy which is capable of generating pressures up to 2000 psi in 5 psi increments. At any pressure in the range from 500 psi to 2000 psi it is estimated that the true pressure at the bottom of the piston is 0.18% less than the nominal pressure with an estimated uncertainty of ±0.13% of the value (95% confidence level). Correction must be made for the fluid head existing between the bottom of the piston and the location of the transducer to be calibrated. (3)

2.1.2 Excitation

The source of excitation voltage for strain gage and potentiometric transducers is a commercial semiconductor power supply capable of delivering up to 200 milliamperes at voltages up to 25 volts, with output variations claimed to be less than 2 millivolts for large load or line voltage changes and less than 0.2% drift during an eight hour period following warm up.

Semiconductor strain gage transducers may show more favorable temperature characteristics when operated from a constant current supply. The commercial semiconductor constant current supply used in this laboratory can deliver currents from 0.2 to 25 milliamperes, with stability claimed to be better than ±0.02% during eight hours following warm up.

The constancy of the excitation voltage is monitored by means of a laboratory potentiometer with ranges for measuring up to 11.11 volts. The limit of error (specified but not further defined by the manufacturer) of a measurement on the 11.11 volt range is stated to be ± (0.006% of the reading + 100 microvolts). To measure excitation voltages greater than this, a precision voltbox can be used as voltage divider at the input of the laboratory potentiometer. Such a voltbox with output voltage range of 1.5 volts can be used to measure voltage with ranges of 3.o, 7.5, 15, 30, 75 volts and higher with a limit of error of the voltage ratio of ±0.02% (limit of error not further defined).

Constant current excitation is monitored with the same laboratory potentiometer by measuring the voltage drop produced by the excitation current across a ten-ohm resistance standard. The resistance value is known within ±0.02%.

2.1.3 Devices for Measuring the Electrical Output

The output of strain gage pressure transducer is measured with the laboratory potentiometer. This instrument has four voltage ranges. These and the respective limits of error (as given by the manufacturer without further definition) are listed as:

0 to 0.01111 volts, ± (0.008% of reading +0.5 microvolt);
0 to 0.1111 volts, ± (0.006% of reading +1 microvolt);
0 to 1.111 volts, ± (0.004% of reading +10 microvolts);
0 to 11.11 volts, ± (0.006% of reading +100 microvolts);

For potentiometric transducers, excitation voltage and output voltage may be measured as for strain gage transducers. Since the calibration of potentiometric transducers is usually expressed in terms of resistance ratio, it is simpler to determine this ratio directly. This can be done by the use of a precision decade voltage divider connected across the excitation voltage to constitute two adjacent arms of a Wheatstone bridge. The potentiometric transducer is connected across the same excitation voltage source and thereby completes the bridges. A sensitive galvanometer connected between divider output and sliding contact of transducer is used as balance indicator. The voltage divider used has a total resistance of 10,000 ohms (order of magnitude of the resistance of most potentiometric transducers) and is described by the manufacturer as having an accuracy of ±0.04% of the indicated ratio.

2.2 Static Calibration Procedure

The performance testing of pressure transducers as part of the "Interagency Telemetering Transducer Program" is currently carried out on three nominally identical specimens. In view of the importance of the static calibrations, particularly the initial ones, adequate and uninterrupted calibration time is necessary. Accordingly, all equipment required for these calibrations is set up and checked carefully on the day preceding the actual calibration. The pressure system is checked for leaks, the piston gage and the electronic equipment are checked for proper operation.

On the morning of the day of calibration, all electronic equipment is turned on to allow sufficient warm-up time for all components to stabilize (including the transducer under test). Forty-five minutes to one hour is usually adequate. The transducer to be calibrated is connected to the pressure source and the connection made up with the recommended force or torque. If no value is given for flush diaphragm transducers, it is necessary to use a "reasonable" torque to assure proper sealing and repeat this torque (by means of a calibrated torque wrench) whenever the transducer subsequently is removed and remounted.

Time and ambient temperature are recorded at the beginning, middle and end of each calibration cycle. A calibration cycle consists of either eleven points (pressure intervals equal to 20% of full range) or twenty-one points (pressure intervals equal to 10% of full range) when this appears warranted by the characteristics listed by the manufacturer. In the calibration system, a high quality valve isolates the transducer from the rest of the pressure generating system. Without previously exercising the transducer the initial calibration point is taken at ambient pressure. For subsequent points, the procedure is to close the valve isolating the transducer from the system and then to admit the approximately correct air pressure to the rest of the system by means of the regulator and input pressure valve. This valve is then closed and the variable volume control is adjusted to increase or decrease the pressure as necessary to float the spinning weights. The isolation valve is then opened and additional adjustments are made as required to keep the weights at the proper level. Input excitation and output voltage are read and recorded. The isolation valve is closed and the procedure is repeated. Care is taken that the pressure at the transducer changes in only one direction so that transition from one pressure to the next is accomplished with a minium of hysteresis error from overshoot.

The calibration is completed when the calibration cycle has been traced first in the ascending and then the descending direction. The final point is taken back at ambient pressure. Normally, an eleven point calibration cycle takes about forty-five minutes; double that time is required for a twenty-one point cycle.

A second and third calibration are performed in close succession to the first one and following the same procedure. When the calibrations are complete, the values of indicated pressure applied by the piston gage are corrected for the effects of temperature and gravity. The recorded output voltages are divided by the corresponding excitation values for strain gage transducers (unless the transducer has a built-in voltage regulator). From these calibration data the slope of the best fit straight line as determined by least squares analysis is taken to be equal to the sensitivity. The least squares analysis can be greatly simplified by holding one set of coordinates constant using whole number nominal values for the pressures, and by extrapolating the actual transducer output values (which correspond to the corrected values of pressure) to those output values which correspond to the whole number pressures.* Errors introduced by this procedure are estimated to be less than 0.001% of the range. The three calibration cycles and subsequent data reduction usually occupy the full day. The other transducers are calibrated on successive days following the same procedure. These calibration cycles yield values for the following performance characteristics: full scale output (B), sensitivity (C), zero-pressure output (D), linearity (E), hysteresis (F), repeatability of sensitivity and of zero pressure (H), over the period of time taken by the actual calibrations.

Resolution (G) cannot readily be determined for strain gage transducers, since their electrical output is essentially a continuous function of the output. For potentiometric transducers, resolution is a function of the total number of wires of the winding over which the sliding contact passes. If this is known, the resolution is simply the full scale output divided by the number of wires. It can be determined experimentally by recording the transducer output on a graphic recorder while changing the input pressure slowly over a small range. The step-like changes in output disclose the resolution of the transducer.

2.3 Friction

Performance of potentiometric transducers, involving two surfaces which are in contact during relative motion may be appreciably influenced by frictional resistance to the motion. The effects of friction can largely be eliminated by moderate vibration and a generally recognized technique of determining the magnitude of the effect of friction is to note the difference between static calibrations made with and without vibration.

It is the practice in this section at NBS to use an ordinary 6

* Example of procedure

Corrected Pressure Value	Extrapolated Pressure Value	Actual Transducer Output Value	Extrapolated Output Value
39.475 PSI		64.37 MV	
	40.00 PSI		65.39 MV
49.392 PSI		83.55 MV	
	50.00 PSI		84.73 MV

volt door buzzer clamped to the case of the transducer being calibrated to generate the vibrations during the testing of potentiometric transducers. During calibration, the desired value of pressure is applied, then the buzzer is actuated for about 5 seconds, and then the output is read.

3. Dynamic Calibration

Since the majority of pressure transducers in measuring systems are expected to respond faithfully to varying pressure, the dynamic performance characteristics of these transducers must be established. Theoretical and practical considerations in regard to this are discussed in detail in a publication describing a number of methods for the dynamic calibration of pressure transducer. (4) Some remarks, however, appear desirable at this point to introduce a description of the dynamic calibration techniques used in the NBS program for pressure transducer performance.

The dynamic characteristics of a pressure transducer can be described by its transfer function (sometimes called system function). The ratio of an operational output of a dynamical system to the operational input causing that output is called the transfer function. (5) In its most useful form, this function is represented by two curves, one showing the ratio of output amplitude (in convenient units) to input amplitude (pressure units) as a function of frequency, and the other showing phase shift (or time delay) between output and input as a function of frequency.

If the transducer is known to exhibit no significant non-linear effects under dynamic as well as static conditions, the input pressure to the transducer at any desired time can be determined from the recorded transducer output with the aid of the system function.

For a very simple "lumped" system, the system function can be derived mathematically by well-known techniques described in textbooks on mechanics. A recent study presented theoretical and experimental results for more complex systems. (6) Experience has shown that most pressure measuring systems cannot safely be considered to be simple systems, nor are the parameters of complex system easily determinable. Accordingly, the dynamic characteristics of these pressure transducers must be determined experimentally. This, of course, is desirable even in the case of a mathematically simple system as a check on the validity of the assumption of simplicity.

The simplest experimental way of obtaining the amplitude frequency response curve and the phase-frequency response curves would be by the use of steady-state sinusoidal pressures of the desired amplitudes over the frequency range of interest. Since presently available methods of producing precisely known sinusoidal pressures are limited both in amplitude and frequency to values below those required for the adequate testing of the majority of commonly used pressure transducers, another technique must be resorted to.

It is possible to derive the system function of a transducer from its response to any transient input whose mathematical description is known. The most convenient one for the purpose is the step function.

The step function for the dynamic testing of pressure transducers requires that the change from one known pressure level to a second known level occur at a sufficiently rapid rate to shock-excite all resonances of interest in the transducer under test (cause the transducer to "ring"). Each pressure level must be maintained for a sufficiently long time to obtain a record of the transducers steady state response. At present the most useful devide capable of generating a stepfunction with rate of rise fast enough to excite the resonances of interest is the shock tube. A recent military specification (13) calls for the use of a shock tube to determine the dynamic response of a pressure transducer. In some applications, the shock tube rise time is too fast, exciting the high resonances not normally of interest. At present, there does not appear to be a reliable way of varying the rise time to suit the transducer under test.

In theory the response of the pressure transducer to a step pressure can be analyzed graphically to yield the system function. Experience shows that the vast majority of pressure transducers tested are complex systems with a number of lightly damped resonances.

Since each resonance has a total phase shift of 180° associated with it, it is quite obvious that a transient with large frequency components on either side of a resonance will be badly distorted, even if the amplitude-frequency characteristics is relatively smooth, unless a very accurate correction to the phase can be determined and applied. In the absence of more complete knowledge than now available regarding the effect on fidelity of errors in both amplitude and phase, conservative practice dictates that a transducer be relied upon to reproduce faithfully only those transients whose frequency content is below the lowest resonant frequency of the transducer. With this limatation the problem is reduced to locating the lowest resonant frequency and, hopefully, the damping associated with it. Theoretical studies indicate that the frequency-response and phase response characteristics for a complex system with a number of lightly damped resonances at frequencies below its lowest resonance will not be appreciably different from those of a single degree-of-freedom (SDF) system with a natural frequency slightly lower than the value of the lowest resonance. The only stipulation is that the next higher resonance be at least an octave above the lowest. Consequently we believe that the theoretical curves for S.D.F. systems will describe the behavior below its lowest resonance for a lightly damped pressure transducer.

The experimental technique developed at the National Bureau of Standards for detecting the lowest resonant frequency of a pressure transducer yields additional dynamic performance characteristics. The technique subjects the transducer to a step pressure by means of the shock tube. The resulting transducer output is fed simultaneously to an oscilloscope (for a photographic record) and to a special magnetic transient recorder described below. The recorder preserves the transducer's transient output which may be played back repetitively, at any convenient time, into an automatically scanning electronic spectrum analyzer. A photograph of the screen of the analyzer produces a picture showing the frequency components present in the transient, and approximately their relative amplitudes.

3.1 Dynamic Calibration Equipment

3.1.1 The Shocktube

The shocktube in the Basic Instrumentation Section of NBS was specifically designed for the dynamic calibration of pressure transducers, and is shown in Figure 1. The tube, of steel, with an internal square cross section of 3 by 3 inches, is 20 feet long. It is divided into a 12 foot compression chamber and an 8 foot expansion chamber separated by a cellulose acetate diaphragm; the 12-foot compression chamber is filled with helium, and the 8-foot expansion chamber is filled with dry air. the ratio of the absolute pressure of the gases in the two chambers is kept constant at 2.7 to 1 over the operating range of pressures.

Upon rupture of the diaphragm (initiated manually), the advance of the helium into the expansion chamber creates a shock wave which travels the length of the 8-foot expansion chamber and is reflected from the rigid end wall of that chamber. The pressure transducer under test is mounted in the center of the rigid end wall of the expansion chamber with its diaphragm or sensing end flush with the inside wall surface.

The amplitude of the pressure step to which the transducer is exposed is calculated by means of ideal gas theory from the velocity of the shock wave and the temperature and pressure of the air in the expansion chamber before the diaphragm is burst.

The range of reflected pressure steps which can be generated by this shock tube is from about 6 psi to 1,000 psi; the duration of the pressure step is about 4-1/2 milliseconds. Its rise time is estimated to be less than 10^{-8} seconds.

The amplitude of the reflected pressure step (pressure rise above the pressure of the undisturbed air in the expansion chamber) is computed from the following relation which is based on ideal gas theory. (4)

$$P_\gamma = P_o \frac{7}{3} (M^2 - 1) \left\{\frac{2 + 4M^2}{5 + M^2}\right\}$$

Where P_γ = amplitude of reflected step, psid

P_o = undisturbed gas pressure, psia

M = Mach number

The velocity of the shockwave is determined by means of a modified "Schlieren" system by measuring the time interval required for the passage of the shockwave between two precisely located optical stations. The Mach number is obtained by dividing the shockwave velocity by the velocity of sound at the temperature of the undisturbed gas. The undisturbed gas pressure is measured by a precision force balance pressure measuring system. Error analysis, indicates that the computed amplituded amplitude of the pressure step (for pressure steps from 50 PSID to 1000 PSID) is correct within ±1.2% of that value with a 95% confidence level. (7) The actual pressure applied to the transducer has an additional uncertainty extimated at ±1% caused by lack of precise knowledge of the slope of the top of the pressure step.

3.3.2 The Magnetic Transient Recorder

The magnetic transient recorder shown in Figure 2 was built to NBS specifications by a manufacturer of electronic equipment. It can record, store and reproduce transients of durations up to 6 milliseconds, containing frequencies between 1 to 100 k Hz and amplitude ranges for sine waves from 1 millivolt rms to 5 volt rms. A built-in synchronizing circuit assures that only the desired transient is recorded. The recorder can store four different transients on separate tracks by virtue of a multiple-head arrangement. Transients are reproduced at a constant repetition rate of sixty per second with negligible spurious output due to transition from end of recorded transient to zero signal level.

3.2.3 The Spectrum Analyzer

The analyzer shown in Figure 2 is a commercially available automatically scanning electronic spectrum analyzer. Its frequency range of1 k Hz to 300 k Hz and its sweep width of about 1 k Hz to 200 k Hz are both continuously adjustable permitting detailed examination of portions of the spectrum within the frequency range. The frequency scale of the display on the analyzer's cathode ray tube is linear, permitting easy interpolation. While the sweep rate of the analyzer is continuously variable from 0.05 to 60 sweeps per second, during anlysis it is set to 0.4 sweep per second. A self-developing camera photographs the display on the cathode ray tube for a period of one minute during the analysis.

3.2.4 The Oscilloscope

The oscilloscope on which the output of the pressure transducer is displayed is a commercial unit with a directly coupled vertical amplifier with adequate sensitivity and good stability. The cathode ray tube of this oscilloscope has a short persistence phosphor which generates the required bright trace for adequate reproduction of the transducer output. A self-developing camera photographs this oscilloscope display also.

3.2.5 Pneumatic Stepfunction Pressure Calibrator

This calibrator (8) is a relatively simple device, consisting of a number of inexpensive components and is shown in Figure 3. The rise time of the generated step pressure is about 0.9 milliseconds (much slower than that of the shocktube) and the initial oscillation superimposed on the step decreases to less than 2% of the step amplitude within 15 milliseconds. The range of pressures of this pneumatic calibrator is 2 psi to 100 psi. The heart of the device is a pneumatically operated quick opening valve which applies air pressure from a large storage tank to the transducer under test. The tank pressure is set to the desired value by a pressure regulator and measured by a precision dial pressure gage. Since the volume of the storage tank is more than 100 times that of the combined internal volumes of the quick opening valve and the fixture holding the transducer, gas flow and temperature change are small. The pressure in the storage tank after the step is applied to the transducer, as indicated on the dial gage, approximates closely the amplitude of the pressure step. Since the step pressure can be kept on for an arbitrarily long period of time, this device is also useful for the investigation of relatively slow, long term characteristics.

3.2.6 Liquid Medium Stepfunction Pressure Calibrator

Based on a design by Dr. Daniel Johnson of NBS, the liquid medium stepfunction calibrator (9) contains a conical valve with long stem in a large pressure vessel. The transducer to be tested is mounted so as to face a small cavity in front of the conical valve. Application of pressure to a piston at the end of long stem of the conical valve causes the latter to close. Pressure of the desired amplitude is built up on the large pressure vessel. The transducer cavity is brought to zero psig by a bleeder valve which is thereafter kept closed. A fast release of the pressure on the valve stem piston relieves compressive stress in the valve stem and the conical valve begins to open. As the pressure in the transducer cavity builds up, opening of the valve is accelerated, so that a pressure step of short rise time is applied to the transducer. As in the pneumatic step-function calibrator, the ratio of the volume of the large pressure vessel to that of the transducer cavity is very large. This makes it possible to infer the amplitude of the pressure step from the indication on a precision dial gage. By careful selection of cavity size, oil viscosity and diameter of the valve stem, a pressure step with a rise time less than 3 milliseconds can be produced at most pressures from 500 psi to 3000 psi with the particular version of the calibrator used in the program. Other models of this calibrator are capable of much faster rise times and higher pressures.

This device is also useful for the investigation of relatively slow transducer characteristics. It requires time consuming adjustment and is used at present only to investigate creep in a pressure transducer designed for liquid pressure sensing.

3.2 Dynamic Calibration Procedures

3.2.1 Shocktube operation

The transducer under test is mounted in the endplate of the shocktube. All electronic equipment is turned on and allowed to stabilize for about forty-five minutes. The gas pressures required in the compression chamber and the expansion chamber are computed, based on the desired amplitude of the reflected pressure step. Although it is generally desirable to subject the transducer to a pressure step with an amplitude equal to its full range, care must be taken to insure that the sum of the undisturbed expansion chamber pressure and the step pressure will not exceed the range of the transducer. The number of cellulose acetate layers required in the diaphragm is based on the difference between compression chamber pressure and expansion chamber pressure. For the cellulose acetate used at NBS, (0.02 in. thick) the safe differential per layer is about 80 psi; one additional layer is used to reduce the probability of premature rupture.

After the diaphragms are put in place, the expansion chamber is briefly pressurized to about 15 psig and the pressure then released. This serves to purge the expansion chamber of remnants of helium from the previous shot. When operating at pressures above about 600 psi, it is good practice to purge twice.

The deflection sensitivity of the oscilloscope is adjusted (on the basis of the transducer sensitivity from static calibration) so that the expected response to the pressure step will not exceed the limits of the cathode-ray-tube screen. This means allowing for about twice the expected output, to accomodate the initially high ringing which frequently occurs. The time base of the sweep is adjusted to permit not only full display of the entire transient of nearly five milliseconds, but also a small section of the undisturbed pressure preceding the step.

The Schlieren system and the frequency counter are checked. The two chambers are then pressurized carefully. Helium is fed into the compression chamber and breathing-quality air into the expansion chamber. The undisturbed gas pressure is measured by a force balance pressure gage and recorded on a strip chart recorder. The gas temperature is inferred from the readings of the three liquid-in-glass thermometer permanently fastened to the top of the expansion chamber.

Finally the magnetic recorder is set into operation. The motor is turned on and allowed adequate time to reach synchronous speed (approximately 2 minutes). The input attenuator is set to the expected signal level, a track is selected, the record length control is set to the desired duration of transient to be recorded, and the trigger selector switch is set for either external or internal triggering. The record reset switch is momentarily depressed, and the recorder is then recording continuously. The direction of rotation of the drum is such that the record is played back next into the reproduce head and finally erased by the erase head before this section of the drum comes up to the record head for further recording. Normally, all that is recorded under these conditions is residual, low-level system noise.

When the correct pressures have been reached, a self-developing camera is mounted on the oscilloscope. The trace position is adjusted so that the step response will start from the bottom of the screen.

After a final check of the servomanometer indication, the pressure connection to its sensing head is shut off to prevent damage during the shot.

The camera shutter is opened and the firing lever is pressed. Immediately after the shot, the camera shutter is closed and the gas in the shock tube is permitted to exhaust.

When the transient signal is fed into the record head, the record time circuit is actuated. This immediately shuts off the erasing process and, after the pre-selected time interval, also gates off the recording amplifier so that no further signals are recorded. Thus only the desired length of transient is preserved on the drum. Since the drum continues to spin at constant speed, the recorded transient is played back repeatedly into the spectrum analyzer 60 times per second. This may be done immediately or after storage of up to three months.

The camera is removed from the oscilloscope screen and without changing any settings the vertical amplifier is calibrated by feeding known dc signals into it and noting the corresponding trace deflections.

When the shocktube reaches ambient pressure, it is opened to remove the spent diaphragms. The end plate is also removed and a cleaning rod is used to remove all pieces of diaphragm material. After the end plate is put back, the entire procedure is repeated for the next shot. With two experienced experimenters, shots can be made about every twenty minutes.

In subsequent shots, the time base of the sweep is adjusted (in conjunction with sweep delay adjustments) to permit dispaly of progressively smaller sections of the initial step response. It is desirable to resolve the resonances present visually from the photographs as far as possible as a check on the spectrum analysis.

It is sometimes desired to investigate the response of the transducer to pressures at fractions of the full range. The procedure described can be modified accordingly.

3.2.2 Pneumatic Stepfunction Calibrator Operation

The output of the transducer under test is displayed on the oscilloscope screen as in shocktube calibration. The procedure as far as the oscilloscope settings are concerned is substantially the same. The desired pressure is adjusted by means of a pressure regulator fed by the laboratory compressed air line and measured by a precision dial gage. Pushing the "on" button on the calibrator actuates a solenoid valve to initiate the pressure step and simultaneously delivers a triggering pulse to the sweep circuit of the oscilloscope. Mechanical delays in the calibrator ensure that the initial portion of the trace shows the transducer output before the application of the pressure step. The high pressure state persists until the "off" button is pushed, thus permitting study of pressure effects over extended periods of time. The oscilloscope screen is photographed with a self-developing camera.

3.2.3 Liquid Medium Stepfunction Calibrator Operation

This device is still primarily an experimental one. In view of this and the fact that it is not used routinely for transducer evaluation, a detailed description of its operation is not included here.

3.3 Analysis of Dynamic Calibration Data

3.3.1 Frequency Analysis of Recorded Transients by Means of Spectrum Analyzer

After adequate warm up time, the spectrum analyzer is balanced according to the manufacturer's instructions. The recorded transient is then played back into the analyzer at the rate of 60 repetitions per second. The analyzer's sweep rate is set to 0.4 sweeps per second (experimentally determined as being the optimum rate for the majority of frequency and sweep range conditions).

The frequency-amplitude display appearing on the cathode-ray tube screen of the analyzer is photographed by means of a self-developing camera whose shutter is kept open for one minute (this time was experimentally determined as being sufficient to present the information sought).

For the first run, the frequency and sweep ranges are adjusted to cover a fairly wide spectrum containing the principal (or most prominently appearing) resonant frequency. This can generally be obtained from the photograph of the transducer's step-function response or the frequency spectrum presented by the analyzer may be searched visually for the largest amplitude signal. All the control settings are carefully noted; then the camera is mounted and the picture taken. Immediately afterward and without disturbing any control settings the analyzer is switched to the output of the built-in audio oscillator that is used to calibrate the frequency scale at three points (both end points and the mid point).

Without disturbing input attenuator settings or bandwidth control (which also affects display amplitude), both sweep width and center frequency-control settings are varied as desired to search carefully the entire frequency range of interest, generally starting at the higher frequencies and working down toward the lower limit which is near 500 cps. The display should always be checked by visual observation before the photograph is taken. Frequency scale calibration is done whenever settings have been changed. The values of the settings are recorded.

The end result is a series of pictures. From them and form control setting values a listing can be made of the shock-excited resonant frequencies contained in the transducer output with a very rough indication of their relative amplitudes. An example is shown in Figure 4.

The electronic spectrum analyzer can show only the Fourier component amplitude in the signal analyzed. It cannot give information on their relative phases, and therefore does not make it possible to obtain the complete Fourier analysis.

An important source of error in the identification of resonances exists in the recorder itself. In order to achieve a flat frequency response some tuned equalizing circuits from part of the amplifiers. These circuits, when shock-excited electrically by the transient under analysis, will ring at their own characteristic resonances. The two most prominent frequencies are about 1.3 k Hz and 4.2 k Hz. These two frequencies can be readily identified as amplifier resonances in most analysis and ignored. Transducer resonances at or very near these frequencies could not be distinguished from the electrical resonances and the transducer analysis is therefore incomplete.

When the analysis of the transducer output covers the frequency range within which these electrical resonances lie, the following procedure should be used. After completing the analysis and the taking of pictures, the transient is carefully analyzed over this frequency range and then erased. Without disturbing any amplitude or frequency settings, electrical square pulses are applied to the input of the recorder and the resulting transients analyzed. Visually the pulse amplitude is adjusted until the display has substantially the same amplitude and shape as that due to the transducer (except for the presence now of only electrical resonances). Point by point comparison of the pictures of these two analysis will help locate true transducer resonances.

3.3.2 Graphic and Visual Analysis of Photographs of Transducer Responses

Additional information on the dynamic characteristics can be obtained from the oscilloscope traces of the transducer's response to the pressure step. Having computed the amplitude of the pressure step (from the shockwave velocity, undisturbed gas pressure and temperature), a line can be drawn on a photograph of the oscilloscope trace indicating the expected response amplitude based on the oscilloscope deflection sensitivity and the transducer's sensitivity from its static calibration. The closeness between this line and the transducer's step response is a measure of the transducer's dynamic response. Ideally the agreement should be within the limits of combined experimental errors. Frequently, the step excited ringing of the transducer prevents good comparison. This is a limitation in the use of the shocktube with its fast rise time. If the ringing appear sinusoidal, reasonable inferences may be drawn by striking an average through the excursions of the ringing and using that to represent the step response. If the ringing persists for the entire 4 1/2 millisecond duration of the step or beyond, a valid comparison is not possible for these shocktube data.

When the step response is obtained by means of the pneumatic or hydraulic stepfunction pressure calibrators this time limitation does not apply, and performance characteristics can be established over a much longer period of time. Care must be taken however that there is no pressure drop due to leakage (particularly at high hydraulic pressures). Stability of oscilloscope characteristics must also be established.

For a lightly damped transducer, the period during which the transducer "rings" is of interest. During this period, the transducer is unable to follow slower pressure variations. If the transducer is sufficiently damped for transient excited ringing to be of short duration, valid comparison with computed values of low frequency pressure variations is feasible. Stepfunction pressure tests of such transducers may uncover non-elastic behavior such as creep. (9)

For simple, damped pressure transducers and often more complex systems, the initial response to a pressure step may yield useful information. The speed of response of such a system is characterized by its "rise time", the time required by the transducer's output to first reach the computed value of the pressure step. The frequency response of complex transducers, such as "cavity" pressure transducers may be controlled by the value of frequency computed from its "rise time" rather than by the lowest resonant frequency obtained from the analysis of the "ringing".

For "cavity" pressure transducers, it is desirable to compute the value of the lowest acoustic resonant frequency, which is primarily a function of the dimensions of the cavity and inlet tube. Confirmation of the existence of this resonance can then be sought in the experimental frequency analysis. A number of reports describe in detail methods for computing responses of pressure measuring systems. (10, 11) The formula given below, obtained from one of the publications, (11) will serve for gas filled systems at laboratory conditions

$$f_o = 17.5 \times 10^2 \frac{D}{LV}$$

f_o = acoustic resonant frequency, Hz
D = inside diameter of tube (orifice) inches
L = length of tube (orifice) inches
V = transducer volume, cubic inches

4. Environmental Tests

4.1 Static Temperature Tests

Static temperature tests are static calibrations performed after the pressure transducer has become stabilized at the desired test temperature.

The transducer is mounted in the temperature chamber and connected through a piece of copper tubing to the pressure source. A thermocouple is attached to the transducer case to monitor its temperature. The temperature chamber contains a blower which circulates air over a heating element and over a dry ice pan and then into the test compartment. A dial thermometer indicates the temperature in test compartment and is used as a rough indicator. An externally adjustable thermostat in the chamber sets the operating temperature within the range of the chamber from -54°C (-65°F) to 177°C (350°F).

Ordinarily, eleven-point static calibrations are performed at each test temperature. When testing two or more transducers of the same type and range, fewer points are sometimes taken for the static temperature calibrations of the second and subsequent transducers.

The temperature range over which the transducer is tested is chosen to leave a margin of safety of about 10°C (18°F) within the claimed operating range of the instrument. The testing is done in two parts. Tests below laboratory ambient temperature are followed by tests at elevated temperatures.

An initial static calibration is performed (after the transducer has been mounted in test chamber and permitted to stabilize at room temperature). For the low temperature tests, the desired low end of the range is reached in three steps, usually of about 25°C each. Then the chamber is permitted to warm up and an additional calibration is performed about halfway between the lower range limit and room temperature. A final calibration at room temperature completes this part. At each temperature, the transducer is allowed to stabilize for about 45 minutes and the transducer case temperature is measured by the attached thermocouple before, during, and immediately after, each calibration.

Tests at elevated temperatures follow immediately, using as initial calibration the one just performed at room temperature. Again the high temperature end of the range is reached in three 25°C steps for the majority of current instruments tested whose upper limit is about 120°C (248°F). If the limit is appreciably higher additional steps are taken. The chamber is permitted to cool down with one calibration performed half-way down to room temperature and again, the final calibration at room temperature. This final calibration also serves to indicate if any permanent changes in performance characteristics may have occured as a result of the temperature tests.

Sensitivity at each test temperature is computed as described in 2.2, and the values, as well as the zero pressure outputs, are plotted as a function of the test temperature.

While these tests as well as static calibrations are performed with constant voltage excitation, some of the newly developed semiconductor strain gage transducers show quite different temperature characteristics when excited from a constant current source. Where manufacturers literature indicates that either type of excitation may be used, static temperature tests are run with both types of excitation.

4.2 Dynamic Temperature Tests

The tests described in section 4.1 "Static Temperature Tests", are not adequate to establish the performance characteristics of pressure transducers operating in a rapidly changing thermal environment.

Many transducers contain temperature compensating components that are designed to minimize changes in sensitivity and zero pressure output over a wide range of temperatures. Temperature compensation is effective only when these components and the sensing elements of the transducer are at the same temperature. Rapidly changing environmental temperatures will tend to set up gradients in the transducer which may cause excessive zero shift, due to the temperature difference between sensing and compensating elements.

Dynamic temperature effects are most pronounced in small, flush-diaphragm pressure transducers. A technique was developed at NBS for observing dynamic temperature effects in such transducers. (12) Briefly, it consists of immersing the sensing end of the transducer into a pool of molten Woods metal at a temperature slightly below the upper limit of the transducer's operating temperature range. The output of the transducer during immersion may be displayed on an oscilloscope with an adequately slow sweep or recorded by an oscillographic recorder for longer time periods. The testing time varies with the instrument, but generally three minutes are adequate from the initiation of immersion. During the test the transducers zero-pressure output will usually show a rapid initial negative shift lasting for a few seconds. This shift reverses and becomes positive, increasing until a maximum is reached, typically after about one minute. After this, the shift will decrease until ultimately the zero shift will reach the value expected from its static temperature characteristics for the temperature at which the transducer finally stablizes.

Tests may be performed at other temperatures within the operating range of the transducer. The technique cannot be used effectively at present for other than flush-diaphragm transducers due to the difficulties of introducing the liquid metal into the transducer cavity rapidly enough.

At the conclusion of the tests, a static pressure calibration is recommended to check on possible damage sustained during the tests. In view of the possibility of damage, dynamic temperature test should be performed last in the evaluation of transducers.

4.3 Steady-Acceleration Tests

The tests which establish the acceleration sensitivity of the transducer are carried out by mounting the instrument on a centrifuge and subjecting it to acceleration forces in various oreintations.

The transducer is normally tested in three orientations.

(1) Cylindrical axis of transducer in line with the applied acceleration and sensing end away from centrifuge center of rotation.
(2) Cylindrical axis of transducer in line with the applied acceleration and sensing end toward centrifuge center of rotation.
(3) Cylindrical axis of transducer perpendicular to the applied acceleration.

(4) Same as (2) with radial position changed 90°.

In each of the positions with zero pressure input, accelerations of 5, 10, 15 and 20 g are applied and the resulting output measured. The results are reported in terms of percent of full scale sensitivity per g.

Two precautions must be taken. The pressure port of the transducer should be covered, otherwise in one of the testing positions the air impact pressure due to centrifuge rotation may cause erroneous outputs. Transducers which dissipate much electrical energy (certain high voltage bonded strain gage transducers in particular) should be covered with a box to prevent air cooling due rapid centrifuge spinning, resulting in outputs not representative of normal use.

4.4 Vibrational Acceleration Tests

The tests which establish the vibration sensitivity of the transducer are carried out by mounting the instrument on the table of an electromagnetic shaker and subjecting it to vibrational acceleration fields in various orientations.

The transducer is normally tested in three orientations used for the steady-acceleration tests (1, 3, 4) Section 4.3. It is subjected to vibrational acceleration forces with a maximum value to 20 g over a frequency range wide enough to include those frequencies which the transducer is likely to encounter in use. The actual acceleration and frequency range obtainable by available equipment are: frequencies between 105 Hz and 7500 Hz at an acceleration level of about 75 g peak-to-peak.

During the test, the transducer output is displayed on an oscilloscope which is watched while the frequency of vibration is slowly varied through the desired range. The vibration amplitude is monitored and adjusted to keep the amplitude relatively constant within equipment limitations. Resonances appear as peaks in the output at certain frequencies. It may be difficult at times to ascribe such peaks to the transducer, rather than to the shaker-transducer combination. The fact that peaks appear simultaneously in the transducer output and in the shaker motion does not necessarily indicate a shaker resonance. One possible way of identifying the origin of resonances is the use of a piece of metal of the weight and size of the transducer as shaker load. If a peak in shaker motion appears at the same frequency as before, this frequency is a shaker resonance.

Frequently, no peaks are descernible. The vibrational acceleration response is then described simply as not exceeding the maximum trace broadening (in terms of the transducer sensitivity) observed (due to internal noise, vibration, electrical pickup) over the frequency and amplitude range tested.

In potentiometric transducers a mechanical resonance of the slider may manifest itself by complete loss of output signal.

A static calibration at the conclusion of the vibrational acceleration tests is desirable to indicate any possible permanent change in the performance characteristics caused by the tests.

5. Electrical Tests

5.1 Tests to Determine Effects of Power Supply Variations

Pressure transducers may exhibit changes in sensitivity and zero-pressure output when operated at excitation values other than the nominal values recommended by the manufacturer.

The tests consist of static calibrations at laboratory ambient conditions and at excitation values both above and below nominal values. If the manufacturer gives a maximum allowable value for the excitation, in addition to the nominal value, the former poses the upper limit for the tests. In the absence of a maximum value, tests are usually performed at excitation values from 50% of nominal to 125% of nominal.

The test starts with an initial static calibration at the nominal value of excitation to serve as reference. The transducer is then disconnected from the excitation source and permitted to cool down for two hours. At the end of this time, the power supply output is adjusted to deliver 50% of the nominal excitation value and the transducer is reconnected. After a stabilization period of about forty five minutes, a static calibration is run. The procedure is repeated for 75%, 100% and 125% of the nominal excitation (and at the "maximum allowable excitation", if that value is given).

Variations in sensitivity and zero-pressure output from corresponding values at the nominal excitation are determined as a function of the excitation value.

5.2 Tests to Establish "Warm-up" Effects

Sensitivity and zero-pressure output of pressure transducers may change somewhat from the time the transducer is connected to the excitation source until complete internal equilibrium is reached. For this reason, a stabilization period of about forty five minutes is considered good practice before static calibrations and other tests.

Under certain conditions of use, a transducer may be expected to perform measurements shortly after being energized. In order to evaluate the performance under such conditions, the following test procedure is followed.

The test equipment including excitation power supply are turned on and permitted to stabilize with the transducer <u>disconnected</u> from the excitation source.

The transducer is connected and a series of three-point static calibrations is started one minute after the connection. The three-point calibrations are made at a zero-pressure point, a full range point, and a final zero-pressure point. The calibrations are made at five-minute intervals during the first half-hour, at ten-minute intervals during the next half-hour, at fifteen minute intervals during the following hour, and half-hour intervals during the following hours.

These calibration monitor closely the initially expected rapid changes and permits data work-up and plotting after the first hour. The tests are stopped when sensitivity and zero-pressure output have been stable for about one hour.

5.3 Contact Noise Test

Contact noise is the result of the variation of contact resistance at the sliding contact of the potentiometric element. The importance of this characteristic depends on the magnitude of the change in contact resistance, the nominal resistance of the winding and the resistance of the load circuit. The higher the load impedance, the less will be the effect of a given contact resistance change.

Equivalent contact resistance may be determined by the circuit shown in Figure 5. With switch S closed the current limiting resistor is set so that the current through the potentiometric element and contact is essentially constant and will not exceed the maximum allowable value for any position of the slider. The transducer is pressureized from zero to about its full scale value at a relatively constant rate, taking about five to ten seconds. During this time the height of the generated noise pips is noted on the oscilloscope. The pressure is released. The resistance R required to produce a deflection on the oscilloscope equal to the amplitude of the noise pips is determined by opening and closing switch S and varying resistance R. The final value of resistance then represents the maximum sliding contact resistance.

6. Special Tests

6.1 Tests to Determine Effects of Mounting Torque

Pressure transducers, particularly flush-diaphragm instruments, may exhibit changes in sensitivity and zero-pressure output when they are mounted in fixtures as a result of case deformation in mounting. Transducers with integral pressure fittings for tubing are not normally subject to this effect.

The tests to determine effects of mounting torque are static calibrations at various levels of mounting torque. (Manufacturer's literature generally gives no information on recommended mounting torque). It is prudent to perform this test early in the evaluation sequence. It is possible to proceed by mounting the transducer in the test fixture and using a calibrated torque wrench to tighten it in increments, running a static calibration at each level of mounting torque (these may be abbreviated calibrations; five points are adequate). The maximum torque used should not exceed 30 inch-pounds, in the absence of any information from the manufacturer.

6.2 Life Tests

6.2.1 Pressure Cycling Tests

The repeated application of pressure stimuli to a pressure transducer may result in gradual but permanent changes in its performance characteristics. Pressure cycling tests are performed to assess these changes.

The equipment for these tests consists basically of a solenoid valve connected to a variable source of air pressure and a switch actuated by a cam driven by a timing motor. The switch opens and closes the solenoid valve at the rate of 3000 cycles per hour. A resettable electromagnetic counter also operated by the motor driven switch totalizes the number pressure cycles. A needle valve between solenoid valve and transducer is adjusted to control the rate of air flow to prevent "ringing" of the transducer. The pressure source is adjusted so that the applied pressure does not exceed the range of the transducer, but is at least 80% of that value.

Pressure cycling is preceded by at least one eleven-point static calibration to establish a reference. After this the transducer is cycled 20,000 times and another eleven-point calibrations is performed. Then cycling is resumed for another 20,000 times and the calibration is repeated. This procedure is continued until 100,000 cycles are reached. Testing in 50,000 cycles steps follows until about 500,000 cycles have accumulated. Steps of 100,000 cycles up to one million complete the procedure. An eleven point static calibration immediately after cycling stops is followed by another one week later. The transducer is allowed to rest in the interval between calibrations.

A similar series of tests may be run on another transducer of the same type and range, but at a pressure level of 125% to 150% of full scale range to assess over-pressure cycling effects.

It must be emphasized that these cycling testing procedures were instituted only recently and as more experience is gained, they may be modified. The procedure and steps indicated may not be optimum for a particular application.

If it is felt desirable to change the procedure, several factors should be kept in mind. The amplitude of applied pressure has a considerable effect on the change in performance characteristics with cycling. Most changes in characteristics occur during the first few thousand cycles. Finally, a portion of the observed changes is temporary as can be seen during rest periods in cycling.

6.2.2 Storage Life Tests

The long term exposure of the transducer to any environment may produce some changes in its performance characteristics.

If the transducer is kept at laboratory ambient conditions and is subjected only to periodic static calibrations, this procedure constitutes a "shelf life" test. To be meaningful, such a test requires detailed information on the transducer's previous history and should continue for at least six months, preferably a full year or even longer.

A more revealing test is one in which the transducer is exposed to an environment other than ambient laboratory conditions, for a long period of time.

If a pressure transducer is expected to measure pressures over an extented period of time at temperatures far removed from ambient-laboratory conditions, it is desirable to expose the transducer to that temperature for a period of time for test.

The recommended procedure is to perform an initial static calibration at room conditions at the beginning of a work week. The transducer is raised or lowered to the desired test temperature and after stabilization, a static calibration is run. After this the transducer is kept at the test temperature until the morning of the last workday of the week, at which time it is permitted to return to room conditions. Periodic calibrations while at the test temperature monitor changes in characteristics. After the transducer has stabilized at room conditions, a static calibration is performed, followed by a final one at the beginning of the next work week. After this, if desired, the whole cycle may be repeated.

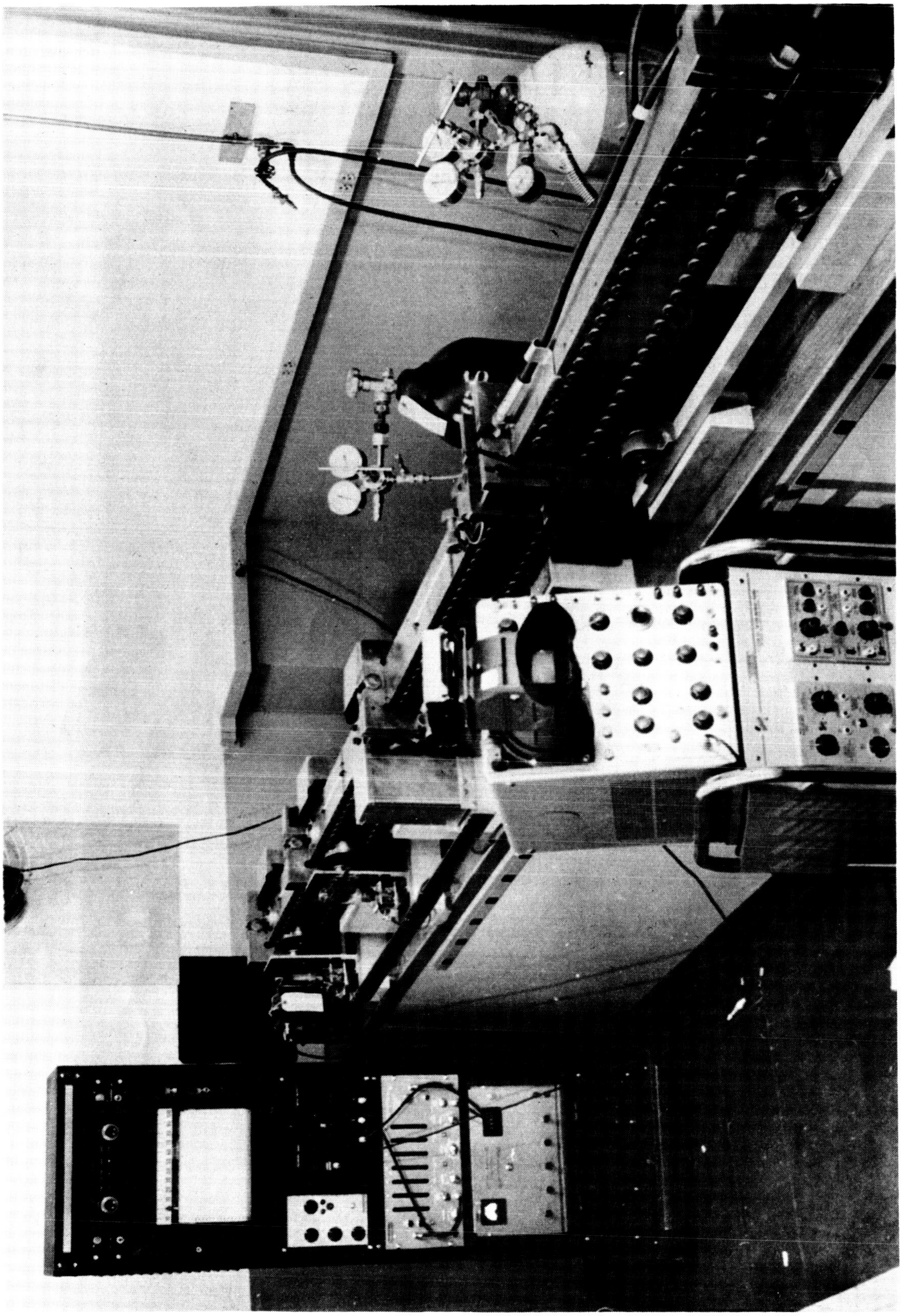

FIG. 1 VIEW OF SHOCK TUBE AND AUXILIARY EQUIPMENT

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Military Specification "Transducer, Pressure".

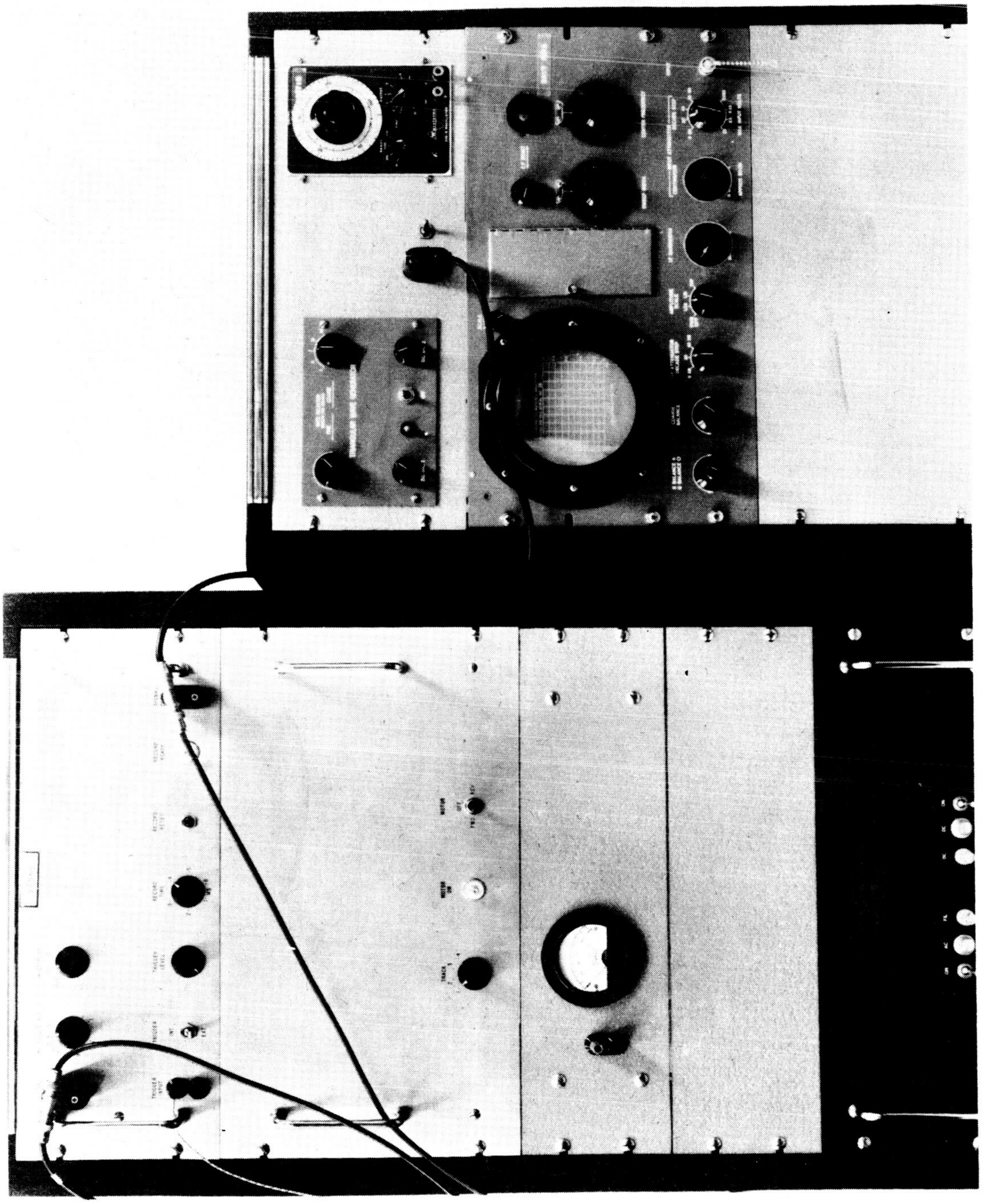


FIG. 2 MAGNETIC TRANSIENT RECORDER AND FREQUENCY ANALYZER

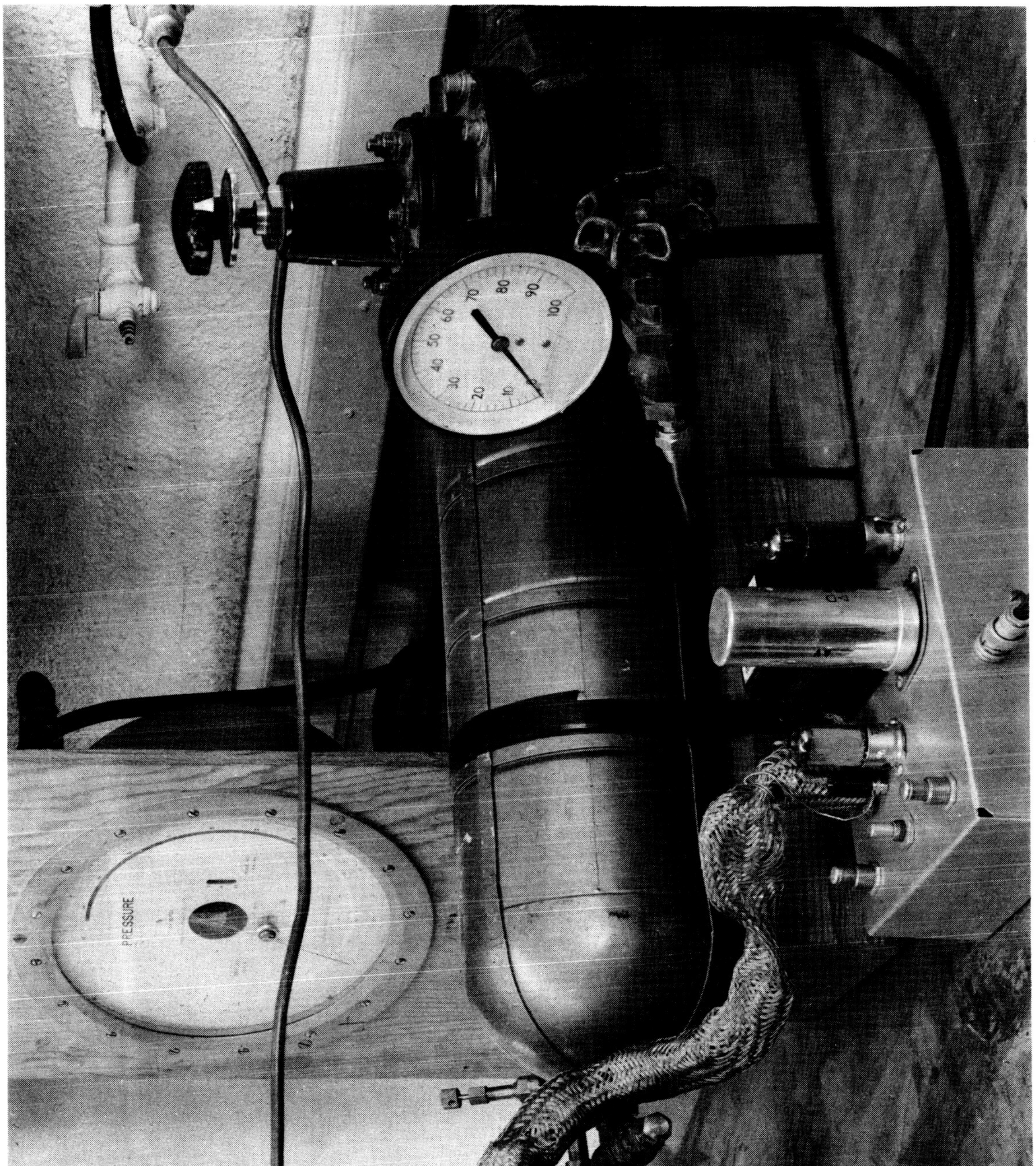
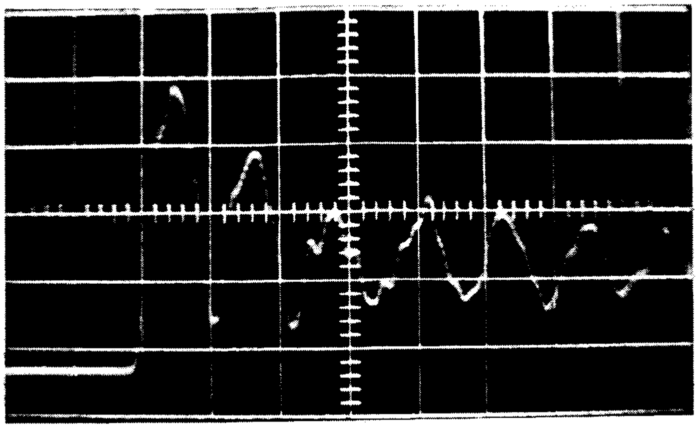
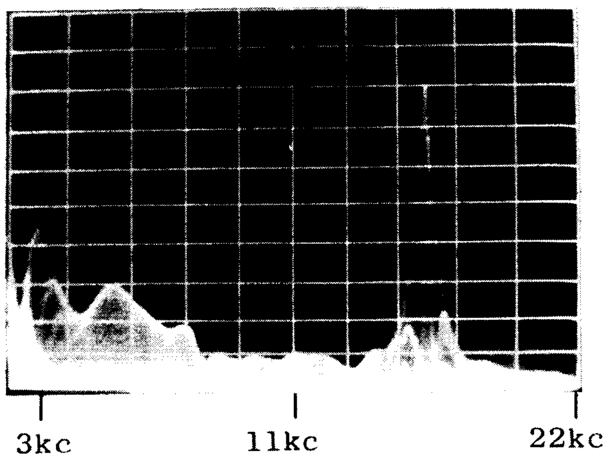


FIG. 3 PNEUMATIC STEP FUNCTION PRESSURE CALIBRATOR



TIME BASE 50 μsec/cm

A RESPONSE OF TRANSDUCER TO SHOCK TUBE PRESSURE STEP OF 52.2 PSI



B FREQUENCY ANALYSIS OF ABOVE SHOCK TUBE RESPONSE OVER FREQUENCY RANGE FROM ABOUT 1.5kc TO 22kc

FIG. 4 SHOCK TUBE RESPONSE AND FREQUENCY ANALYSIS OF FLUSH DIAPHRAGM UNBONDED STRAIN GAGE PRESSURE TRANSDUCER

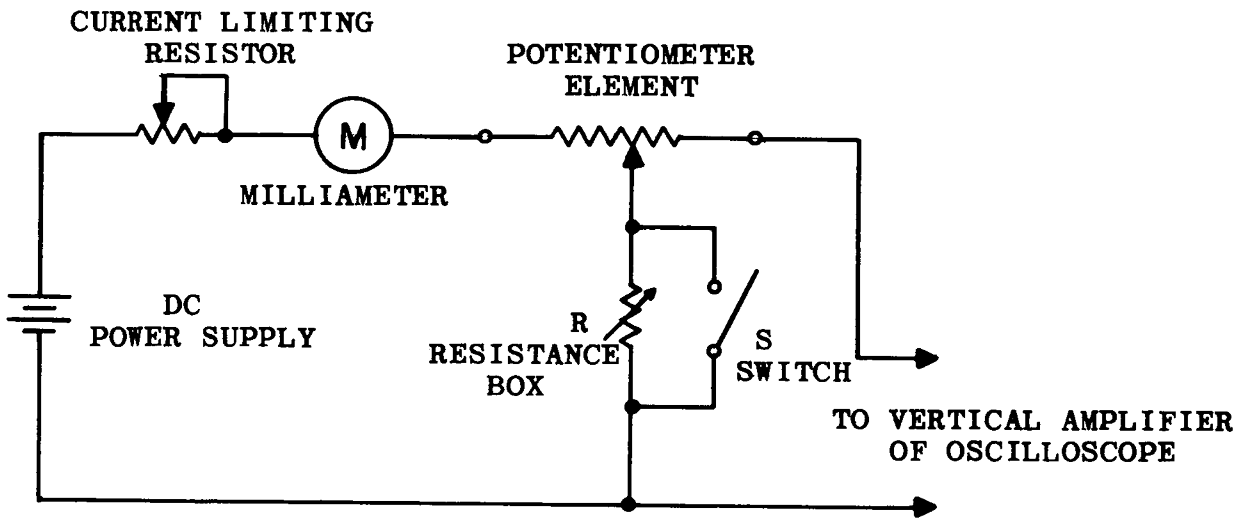


FIG. 5 CIRCUIT FOR DETERMINING EQUIVALENT CONTACT RESISTANCE.

* U.S. GOVERNMENT PRINTING OFFICE: 1967—251-023/61